Advanced Electromagnetic Educational Visualization

SURF
Summer Undergraduate Research Fellowship

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ABSTRACT

In the realm of university-level Electromagnetics education, the need for concrete representations of abstract theories is paramount. Concepts such as three-dimensional coordinate systems, various surface and volume integrals, as well as the visualization and physical representation of electric and magnetic fields, pose challenges for students.

This project created demonstrations and animated visualizations tailored to facilitate the learning process for students in the field of Electromagnetics. Softwares including Matlab, COMSOL, CST and Geogebra were investigated and demos were generated to illustrate certain concepts.

Sub-Proj. 1 Matlab

Matlab - MATLAB® live scripts are interactive documents that combine MATLAB code with formatted text, equations, and images in a single environment called the Live Editor. In addition, live scripts store and display output **alongside** the code that creates it, which would be convenient for students to learn from the abstract equations and related codes.

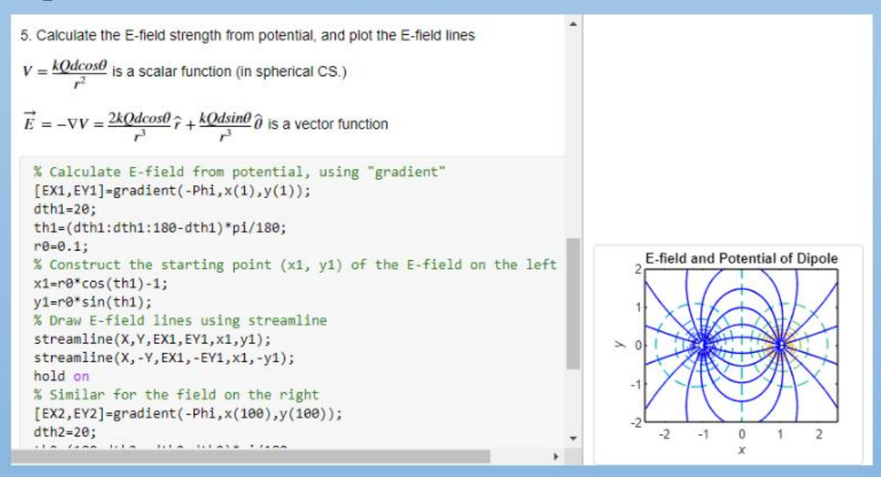

5. Calculate the E-field strength from potential, and plot the E-field lines
$V = \frac{kQdcos\theta}{r^2}$ is a scalar function (in spherical CS.)
$\vec{E} = -\nabla V = \frac{2kQdcos\theta}{r^3}\hat{r} + \frac{kQdsin\theta}{r^3}\hat{\theta}$ is a vector function
% Calculate E-field from potential, using "gradient"
[EX1,EY1]=gradient(-Phi,x(1),y(1));
dth1=20;
th1=(dth1:dth1:180-dth1)*pi/180;
r0=0.1;
% Construct the starting point (x1, y1) of the E-field on the left
x1=r0*cos(th1)-1;
y1=r0*sin(th1);
% Draw E-field lines using streamline
streamline(X,Y,EX1,EY1,x1,y1);
streamline(X,-Y,EX1,-EY1,x1,-y1);
hold on
% Similar for the field on the right
[EX2,EY2]=gradient(-Phi,x(100),y(100));
dth2=20;
E-field and Potential of Dipole
y
x

Figure 1. E-field and potential of electric dipole calculated and plotted using Matlab LiveScript.

List of models:

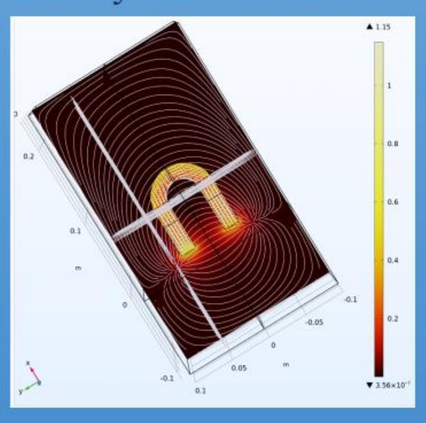
Static electric fields: dipole, positive charge(s), dielectric/conducting spheres in uniform electric field, charge-carrying plate/plates;

Static magnetic fields (2D/3D plotting): single/pair straight line(s), coil;

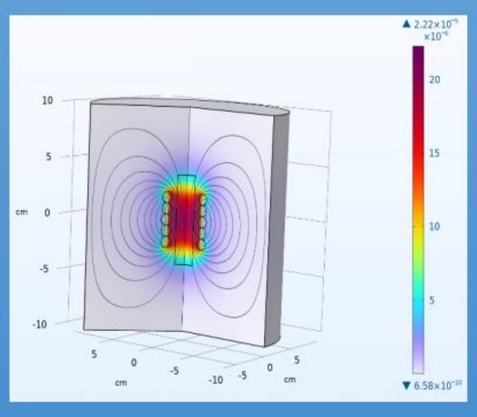
Lorentz' forces: charge-carrying particle's movement in static E-/H-fields.

Sub-Proj. 2 COMSOL

COMSOL - COMSOL® Multiphysics is a general-purpose simulation software based on advanced numerical methods. It's been used to simulate designs, devices, and processes in all fields of engineering, manufacturing, and scientific research. Although we used it to visualise the Electromagnetic fields, its ability extends to all Physical sub-areas.



← Figure 2. H-field of a U-shaped magnet.



→ Figure 3. H-field of a solenoid.

List of models:

Magnets: ring, U-shaped, single/pair of bar(s);

AC supplied current-carrying wires: single coil, solenoid with different gaps, parallel plates.

Sub-Proj. 3 CST Microwave Studio

CST - CST Studio Suite® is a high-performance 3D EM analysis software package for designing, analyzing and optimizing electromagnetic (EM) components and systems.

It was mainly used in antennas designs and microwave applications, but it is also excellent in demonstrating the wave propagation in EM eduation with animations.

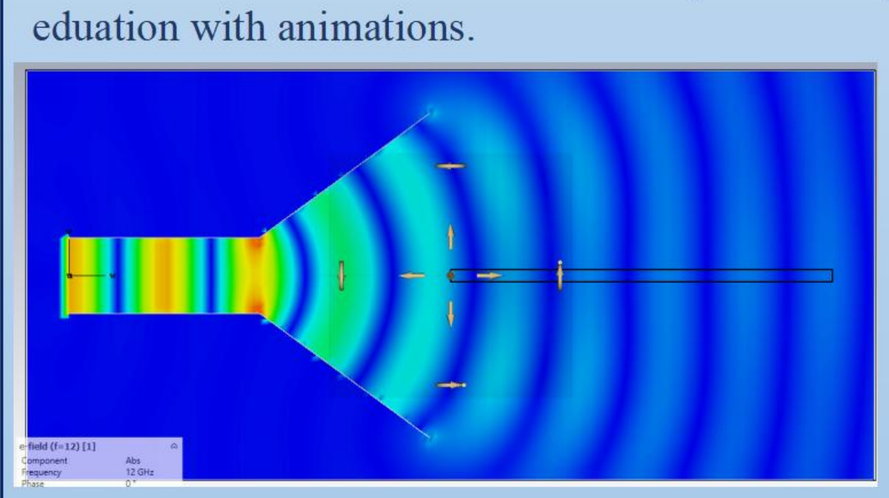


Figure 4. TEM wave radiated by a horn antenna and propagate in free space.

List of models:

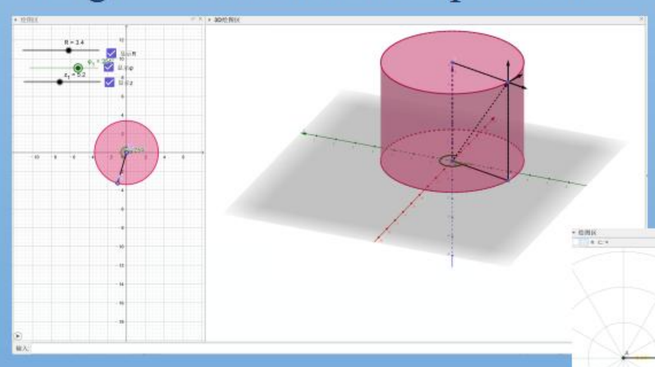
Propagation: waveguides, microstrip lines;

Radiation: patch, horn, waveguide-horn feeding, SMA-horn feeding.

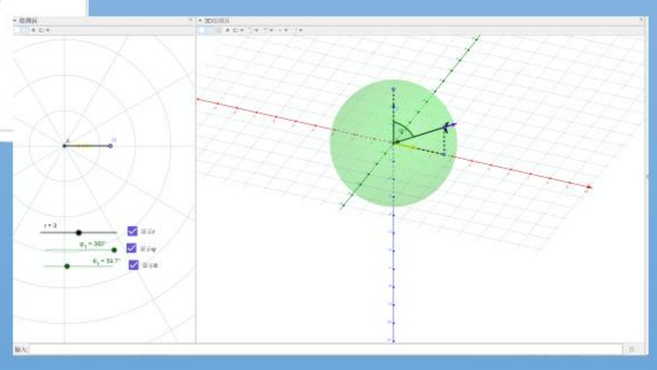
Sub-Proj. 4 GeoGebra

GeoGebra - GeoGebra Calculator Suite is a dynamic mathematics app connecting geometry and algebra. It could introduce the abstract concepts in interactive ways.

It was mainly used in mathematics, but also suitable for Physics. In this project, we investigated the available resources for EM, and designed some new to explain the 3D coordiantes and curl.



← Figure 5. Interactive demo of the cylindrical coordiante system



→ Figure 6. Interactive demo of the spherical coordiante system

List of models:

Coordiante Systems: cylindrical, spherical;

EM models: curl of a general field, related magnetic field.

CONCLUSIONS

This project addressed the need for concrete representations in university-level Electromagnetics education by creating tangible demonstrations and animated visualizations. Utilizing software tools such as Matlab, COMSOL, CST, and GeoGebra, we effectively visualized three-dimensional coordinate systems and complex E- and H-fields, enhancing student understanding. Interactive models of electric and magnetic fields were generated, emphasizing critical characteristics for optimized learning. These resources were designed for seamless integration into existing curricula, significantly improving the educational experience.